Technical Proposal

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Technical Approach

1 Overview and Significance

1.1 Overview

Maintaining and cultivating a diverse, world-class Science, Technology, Engineering and Mathematics (STEM) workforce is critical for maintaining the superiority of the U.S. Navy and Marine Corps. Creating a systematic STEM educational pathway for sustainable workforce development for inclusive and diverse U.S. citizens, regardless of technology domains, is of great interest to the United States Navy and beyond. Our long-term objective is to advance the education of next-generation STEM workforce with strong skills in key technical areas and human team effectiveness. To achieve the long-term objective, the goal of the project is to develop a new active learning approach for inclusive and diverse workforce, with a focus on autonomy and artificial intelligence, that **integrates students-oriented hands-on learning, problem-based learning, and human teaming effectiveness/dynamics learning with diverse STEM topics, namely, 3D printing, programming/software, hardware, human-computer interface, data science, autonomy, and artificial intelligence**. A key challenge is to address the dramatic differences between academic environment (creativity/knowledge-driven) and industry environment (solution/team-driven). Hence, our proposed solution is to integrate the learning of technical skills (academic) and communication/teaming/management skills (industry) for the creation of an active lifelong learning behavior, which is critical for the maintenance of both technical and workforce superiority of the U.S. Navy and Marine Corps.

To address the aforementioned challenge systematically, the overall objective of the project is to create a systematic and integrated academic-industry active learning environment that integrates academic education and industrial training/internships in a unified framework. Specifically, the new learning environment seeks to advances the current STEM education from passive and single-objective education to active and multi-objective education. The key idea is to blend the learning of diverse technical-oriented STEM topics into teaming-oriented hands-on learning, problem solving, and human effectiveness/dynamics learning such that STEM education evolves from a technical-oriented education paradigm to a more balanced technical-mentoring-teaming-management-oriented education paradigm. Such a paradigm change is essential for next-generation active STEM education that merges technology explosion and human effectiveness, especially considering diverse background and experiences from different students. Developing such a new paradigm and the associated active learning approach will offer: (1) creativity: curiosity-based problem identification, strategic planning, and decision making, (2) critical thinking: problem-solving capabilities through trail, failure, learn and success, (3) teaming: from team working to team interaction, effectiveness, dynamics, and optimization, and (4) diversity: view and mindset of integrating and leveraging teams with diverse background and experiences.

1.2 Objectives

The overall architecture of the proposed new active learning STEM education approach is shown in Fig. 1. The new architecture can be regarded as the integration of academic education and industrial training/internships for the creation of a dynamic and integrated academic-industry learning

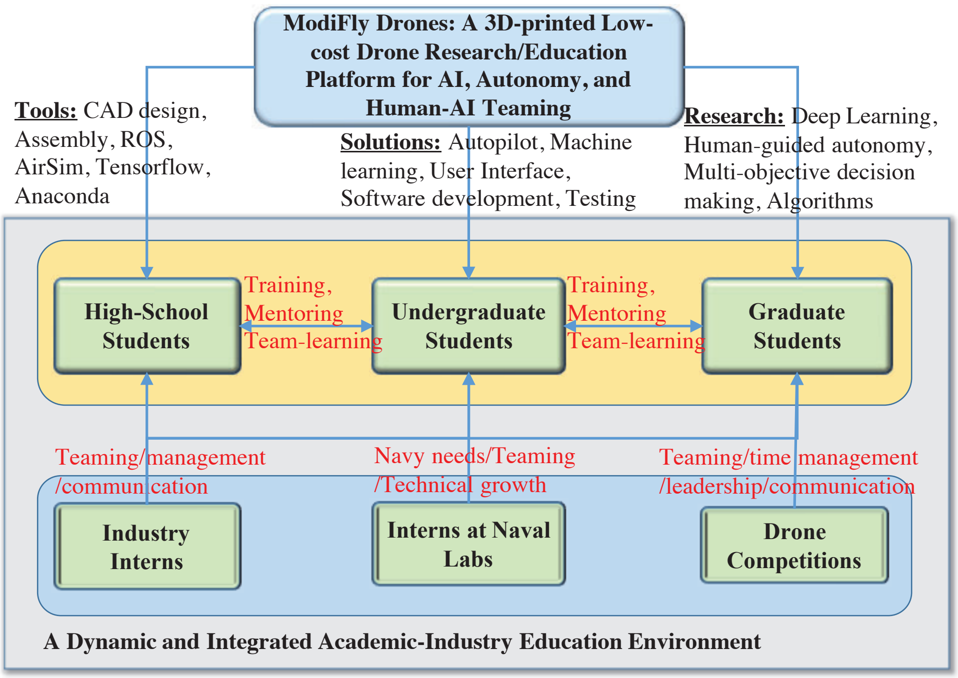

Figure 1: The proposed new active learning STEM education approach.

environment. Different from the traditional STEM education approaches that focus on the learning of various technical topics and areas, this new architecture emphasizes the balance/integration of academic training and human teaming effectiveness training for the seamless transition from STEM education to STEM workforce development. In particular, this new approach focuses on the training of not only critical skills in fundamental tools, solutions, and research in AI and Autonomy, but also essential mindsets in teaming, collaboration, time/task/progress management, communication, and leadership. Two unique features in this STEM education projects are (1) learning from the state-of-the-art teaming/management experiences in industries for their adoption in academic environments, and (2) student-lead teaming and project management. Hence, the key goal (and also success metric) is the growth of individual students in team environments through learning from teammates, lab members, interns at industries and labs, and execution via trial and error. To maximize the impact of the project on students with diverse background, the project will train high school students, undergraduate students, and a graduate student with a diverse and inclusive background, especially minority and underrepresented students. Additional students will be trained by leveraging supports from, e.g., grants from ONR, ARO, and ARL, Office of Undergraduate Research (Louis Stokes Alliance for Minority Participation) and KLESSE College Research Experience for Undergraduate program.

Towards designing the new active learning STEM education approach, the project focuses on three essential thrusts:

(1) Diverse Hands-on STEM Topics. Built on our current ModiFly Drones project, this thrust focuses on the training and education of next-generation workforce with rich hands-on technical skills on autonomy, artificial intelligence, and unmanned systems. In particular, we will train students on various skills, including 3D printing (CAD design and manufacturing), circuit design

(communication, power management, and serial connection), data science (Anaconda, Matlab, and Python), AI (Tensorflow, deep neural network, and reinforcement learning), robotics (assembly, autopilot, ROS, AirSim, autonomy, and human-guided autonomy), and software design (user interface, modular management, ground station, and command/control). Our current ModiFly Drones project has created a basic drone platform using mainly 3D-printed parts with a basic user interface that can support several modules, including FPV camera, LED light show, gripper, GPS, and LIDAR. Our goal in this thrust is to (1) refine these existing modules for reduced costs, ease of assembly, and light weights, (2) create new modules/components, including an optical flow module for indoor applications, an onboard computing module for machine/deep learning, a module to transform drones into ground robots, and a friendly user interface for nonexperts, (3) implement and evaluate existing and newly developed AI and autonomy algorithms, and (4) create training and education modules for new high-school and undergraduate students to learn and build existing and new modules with their preferred functionalities. One graduate student will also be working with the undergraduate students to develop and test onboard computing modules for implementing advanced AI functions, such as onboard target recognition, autonomous flight, human-guided flight and teaming.

(2) Human Teaming Effectiveness/Interaction Topics. Different from the first thrust whose goal is to build diverse fundamental technical skills for students to master key technologies and hands-on experiences, this thrust focuses on the training and education of next-generation workforce with adequate and professional teaming, interaction, management, and leadership skill development, via learning from team members and internship experiences. Past and current students from the ModiFly Drones team have conducted internship opportunities in national labs (JHU APL, ARL) and industrial companies (Amazon, Dell, Michelin), through which they have learned new teaming, management, and interaction skills. After deliberation and debate, the team started adopting two main teaming strategies: (1) implementing Design/Demo Doc for the team to write individual goals/plans, including objectives, business justification, and alternatives, and (2) updating daily in Slack channel on what was done yesterday, what is to be done today, and what the blockers are. With the new implementation of these two strategies, the team is able to work more efficiently and independently. Another advantage is that each team member needs to "defend" his/her plan in front of the team while provides critical feedback for others. The two different roles help train the students to think from both perspectives (designer and customer). Throughout the project, we will develop additional human teaming effectiveness, interaction, leadership and communication skills via, e.g., (1) refinement of these two strategies considering the limited time of students on research projects, (2) effective time management of diverse tasks via task decomposition and team task optimization, (3) leadership development through acting as seasonal group leads/managers, and (4) seasonable demo presentations and talks.

(3) Testing, Evaluation, and Broad Impacts. This thrust focuses on testing and evaluation of the new active learning STEM education approach via different activities. The first activity is the demonstration of team efforts in capstone project competitions held at UTSA every semester. The competition features all capstone projects from the KLESS College of Engineering and Integrated Design, including demo, presentation, and evaluation by industry companies and academic professionals. Our undergraduate students will present their new design/capabilities at the competition. Another competition is the ECEDHA Senior Design Showcase held yearly for institutions from the Southwest Region (Texas, New Mexico, and Arizona). Our team won the first prize and the Entrepreneurial Award (`https://esdshowcase.org/2022-award-winners/`).

In addition, we will train/educate new high-school and undergraduate students on various aspects of the drone platform and AI/Autonomy capabilities and conduct outreach to local community via, e.g., drone competition including high school and college students (`https://2022.dasconline.org/student-unmanned-aerial-systems-competition/`) and local event (ForceCon 2022), and broader communities such as local middle schools via creating educational modules and hosting summer visitors/camps. Additional UAV competitions (`https://www.computer.org/publications/tech-news/events/uav-2022`) may be utilized to train the team's organizational, teaming, management, and communication skills under time and budget constraints.

1.3 The Current State of Knowledge and Its Limitations

Robotic STEM education plays an important role in the education and training of next-generation workforce. Numerous activities have been conducted to bring research on robots and autonomous systems to students at their various learning stages. For example, the authors in [1] focuses on evaluating the impact of an autonomous robotics competition for STEM education. Their studies from students at 5th-12th grade show that robotics competitions can help improve students' study of math and science after the competition. In another reported effort on robot competition [2], the studies therein show that "hands-on, project-based and goal-oriented learning experience that an educational robotics competition provides has long-lasting impacts on students' learning and motivation for further exploring in STEM or STEM related fields". Other relevant efforts include, e.g., (1) design of robotic platform for STEM education [3], (2) inclusion of autonomous driving in undergraduate education through project-based learning [4], (3) low-cost and modular co-robot in pre-college education [5], and (4) exposure of youth age 9-14 through robotics camps, clubs, and competitions [6]. A recent survey article on robotics STEM education for K-12 [7] shows that robotic STEM education can help develop creative thinking, improve problem solving skills, and increase motivation, engagement and attitude towards future STEM careers.

Artificial intelligence (AI) has become an transformative technology that starts to revolutionize numerous sections thanks to the development of deep neural networks [8; 9], deep reinforcement learning [10; 11], and their broad applications [12]. Numerous AI STEM activities have been reported towards the integration of AI technologies in STEM education. For example, the authors in [13] proposed a new education model that connects AI with practical problems in a playful environment. In another effort reported in [14], AI solutions were used to identify the best guidance time for active guidance and active learning. In [15], it is reported that AI can help educators create learning process for long-life education. A recent workshop hosted by NSF reported that the use of AI to transform STEM is still at its early stage despite the consensus agreement that AI can potentially transform STEM education [16].

Recognizing the importance of developing a more diverse and inclusive STEM for U.S. Navy and DoD, some literature review was also conducted to understand some unique challenges and opportunities for STEM education. Some preliminary analysis shows that important efforts have been made towards new course contents [17; 18; 19], new education/lab platforms [20; 21; 22], and new teaching methods [23; 24; 25]. These advances are critical for timely knowledge delivery, but its effectiveness can vary significantly from different groups of students. This is especially true for minority and underrepresented student groups. Minority and underrepresented student groups often face challenges in their higher education, including cultural/psychological barrier, guidance mismatch, lack of confidence, and lack of learning opportunities. In a recent paper [26], the authors studied the minority education, especially women education, in the areas of big data, analytics, robotics and artificial intelligence. "Ways for learning' and 'self-efficacy' are identified as key factors in minority education. In other words, developing new STEM education approaches with self-efficacy is critical for minority and underrepresented groups.

One key limitation in the existing STEM education approaches is the lack of addressing numerous essential components in STEM education progress. Fig. 2 illustrates the key components in STEM education progress based on the PI's mentoring experiences. The bottom two tiers, namely tech primitives and tech awareness, focus on the training of students with critical technical skills and mindsets. The two tiers on top of these two are team primitives and team awareness, which focus on training students with basic communication skills as well as high-level communication awareness such as teaming effectiveness, dynamics, and optimization. Indeed, the synchronization of the four components is a must towards STEM education for next-generation diverse and inclusive workforce development. Our focus in this project is on developing and testing a new education approach that synchronizes these four tiers.

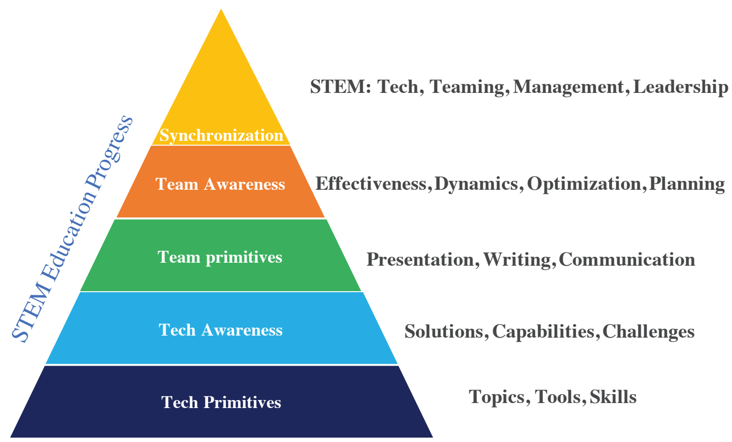

Figure 2: An illustration of STEM education progress.

2 Project Plan and Specific Objectives

2.1 Diverse Hands-on STEM Topics

2.1.1 Background and Objectives

Equipping students with rich and diverse hands-on STEM topics is critical for building the "tech primitives" and "tech awareness" in the STEM education process. For artificial intelligence (AI) and autonomy, this is especially true because of the diverse topics or areas in AI and autonomy, including, e.g., deep neural networks, computer vision, supervised learning, reinforcement learning, human-guided learning, robotic modeling, control, data-driven decision making, human-robot collaboration/teaming. Although it is essential to learn these technical aspects of AI and autonomy, the hands-on aspects are critical for the development of practical skills. Some key hands-on aspects include, e.g., CAD design, assembly, ROS, AirSim, Anaconda, Tensorflow, 3D printing, software development, algorithm implementation, and user interface. Towards building next-generation workforce with critical "tech primitives" and "tech awareness", the *objective* of this thrust seeks to create a flexible, modular, and AI-enhanced drone platform for training students with diverse hands-on technical skills. Another objective is to design a low-cost and user-friendly drone research/education platform.

2.1.2 Preliminary Activites

Current drones in the market lack the ability to quickly adapt to situations and the opportunity to easily upgrade components. Options include complete solutions with locked system components or custom drones that can be difficult to assemble without extensive research into compatible components. Our goal is to create a new drone platform that is compatible with several commonly used engine systems while maintaining a lightweight form factor. We focus on the use of 3D-printed parts in our drone with the goal to reduce cost to build and repair. We also want to make our design simple enough for others to design their own modules/components for their own needs using SOLIDWORKS. Our objective is to create an education platform that can train students with rich skills and promote their development of new skills via student-led team learning.

Figure 3: Modular drone with 3D-printed parts (top) and its exploded view (bottom).

The PI's team started working on developing such a modular drone platform in Fall 2021. Our design objectives include customizability, upgradability, and affordable. Customizability allows the drone to be quickly adapted to fit a variety of roles, thus eliminating the need to have one drone for each task. Upgradability enables the user to improve parts of the drone, like cameras, or develop their own upgrades. Affordability allows the adoption of drones in research, education, and beyond, due to the use of 3D-printed parts in the designed drone platform. Another benefit of the use of 3D-printed parts is the ease of replacing broken parts by users without the need for sending drones to manufactures for repair.

Fig. 3 shows our current design, named "ModiFly", and its exploded view. Our ModiFly drone has been designed to be open-framed for the main assembly, which allows proper airflow through systems with customize changes based on user preference. In black, the connectors are shown to identify where quick connections can be made on the drone. The exploded view (bottom figure of Fig. 3) illuminates a broader range of removable pieces that will require limited/no tools. The typical cost for a base drone ($271) includes: (i) Flight controller and video transmitter ($140); (ii) Battery ($22); (iii) 4 Motors ($40); (iv) Propellers ($15); (v) Filament ($6.50); (vi) Connectors ($7); (vii) LiDAR ($25); (viii)Bluetooth ($8); and (ix) misc (wiring, screws, etc., $7).

We have created numerous modules that work with our ModiFly platform, including FPV camera, LED light show, gripper, GPS, and LIDAR. These modules are plug-and-play supportable. To ease the detection and switch among different modules, we developed a software user interface, shown in Fig. 4, for users to tell the drone which modules are attached.

2.1.3 Proposed Activities

Based on the newly developed ModiFly Drones platform, the proposed activities include (1) training of new students on diverse STEM topics centered around the new platform, and (2) initialization of additional emerging STEM topics in AI and Autonomy.

Training of new students on diverse STEM topics: The PI and his team recognize the importance of training students with necessary technical skills in various STEM topics for workforce development in AI and autonomy, especially for minority and underrepresented students. Hence, our key objective here is to prepare training modules on diverse STEM topics based on the new ModiFly Drones platform. In particular, we will develop training modules for CAD design, ROS, AirSim, Assembly, Circuit Design, 3D-printing, Autopilot, Anoconda, Computer Vision, User Interface Design, Software Development, and Testing. We have trained 2 undergraduate students on these topics, who are currently working in the lab to continue their own development work. In this project, we will train 3 new undergraduate students on these topics and prepare them for their technical skill development ("tech primitives") towards the creation of their own modules/solutions/capabilities. Recognizing the importance of engaging students at their early learning stages, we will also train 2 high-school students during summer time. Our focus will be on training them on these basic skills while connecting them with other undergraduate students to create teams for team projects that fit their own interest and goals. Although the 2 high-school students will be trained during summer time, they will continue working with our students in Fall/Spring with the goal to train them on the development of their own modules/solutions via teaming along with the undergraduate students. The PI has established connection with local high schools with particular interests in robotics. The recruited high-school students will serve as lab representative to recruit more students for their training on the STEM topics mentioned above. It is worthwhile to emphasize the "active learning" nature in the training and education process. First, we will focus on self-motivated learning of modules and components towards their interests and goals because it is important for students to connect technical primitives with technical awareness from their own learning and understanding. Second, discussion and idea exchange among team members is essential for team active learning towards solving new, challenging, and interesting problems of their own. Third, the students are highly encouraged to take lead on their projects through trial and error. Learning from failure is critical for them to actively engage themselves in identifying issues and creating innovative solutions.

Figure 4: Software user interface for detection of modules.

Initialization of additional emerging STEM topics: The rapid growth/development of STEM topics in AI and autonomy requires us develop new STEM topics, especially those emerging ones, such as machine learning, deep learning, drone swarm, and human-swarm teaming. One key challenge is to develop modules that address the limitations, e.g., power and payload constraints. Toward this objective, we plan to develop a lightweight machine learning model trained on images relevant to drone operations via two potential options. The first option is to create a neural network from scratch that meets the exact needs of our drone. The second option is to shrink and train an existing neural network model. The second checkpoint is to determine the optimal processor for machine learning module. We will achieve this by evaluating the best neural network model on several low-power single-board computers to determine the most suitable option for the development of our own machine learning module. After the machine learning module is complete, we will use the module to perform successful autonomous test flights and study the emergent behaviors of an AI-enhanced drone swarm. After some preliminary investigation, we have laid a basic plan to use Google Coral board and Coral camera as our potential solution. We will work on flashing the Coral board and then design and print a module to hold the Coral board and camera. Afterwards, we will work on software that integrates the machine learning module into the drone's control stack. We will implement and train neural network models and advanced AI/autonomy algorithms, such as target recognition, autonomous flight, and human-guided swarm, onboard the drone. During the process, the undergraduate and graduate students will actively learn how to balance the hardware, software, and algorithmic advantages and disadvantages for the creation of system-level solutions and capabilities. Finally, we will design a friendly user interface that supports easy implementation and testing of AI/autonomy algorithms for both experts and nonexperts.

Developing the aforementioned new emerging STEM topics requires the training of students with different background from different perspectives. The 3 undergraduate students will be trained on advanced topics including deep learning, neural networks, algorithm training, and advanced human-guided autonomy algorithms. At the same time, 1 graduate student will be trained on the drone platform to understand the hands-on operations and limitations. The cross-training of the 3 undergraduate students and 1 graduate student will be conducted for them to bridge the technical gap in order to move the AI/Autonomy research to its application in our ModiFly drone platform.

Overall Expected Outcomes: The overall expected outcomes for this thrust include (1) development of training modules on broad STEM topic related to AI and Autonomy, (2) training and education of 3 new undergraduate and 2 high-school students on essential technical skills for the development of their own solutions/capabilities, and (3) (cross-)training and education of 3 undergraduate students and 1 graduate student to create new modules on emerging STEM topics with a focus on machine/deep learning and human-guided UAV swarm.

2.2 Human Teaming Effectiveness/Interaction Topics

2.2.1 Background and Objectives

Equipping students with appropriate human teaming effectiveness/interaction mindsets is yet another key component in the training and education of next-generation workforce in Autonomy and AI because of the need for communication, teaming, planning, execution, and leadership in many, if not all, science and engineering disciplines. For minority and underrepresented students, providing appropriate training and education on various human teaming effectiveness/interaction topics is critical for their career success because of some unique challenges they face (please check Section 1.3 for more details). Towards developing an inclusive and diverse workforce in autonomy and AI for U.S. Navy and beyond, the *objective* of this thrust is to create some unique training and education modules for the improvement of students' teaming effectiveness through active learning of team interaction, effectiveness, dynamics, and optimization for building "team primitives" and “team awareness” in STEM education process. Another objective is to apply the learned teaming techniques in their own research projects/tasks for the refinement and improvement of their teaming skills via actively interacting with other students. Our key philosophy is that industry companies have much richer experiences in teaming, management, and human effectiveness, which should be leveraged in the education and training of human teaming skills for our students.

2.2.2 Preliminary Activities

Our team members have conducted internship opportunities in national labs (JHU APL, ARL) and industrial companies (Amazon, Dell, Michelin), through which they have learned important teaming, management, and interaction skills. We have adapted these techniques in our daily activities. The three essential human teaming effectiveness/interaction topics are (1) switch from PI-lead initiatives to student-lead initiatives, (2) creation of effective plan-justification-execution-feedback loop, and (3) frequent and effective team conversation/update. The following will provide a brief summary of some key activities for each topic.

For the first topic from PI-lead initiatives to student-lead initiatives, we initialized a new joint project-team mentor program, motivated by the students’ internship experience at JHU APL. The main idea of the new initiative is to distinguish between project mentor and team mentor. The project mentor is typically the PI, who provides general guidance and support *without* managing team activities. The team mentor is typically a student lead, who manages and supports daily team operations. One unique feature is to avoid unnecessary micromanagement and allow active learning of teaming skills because the daily operations are managed within the student team. Note that the team mentor may change from one to another based on specific team tasks at a given period, hence allowing students play different roles to gain different experiences. Project mentor and team mentor often set up weekly meetings to mainly go over the progress and challenges. Project mentor will get involved further if such a need arises, but will leave decisions to the team. We utilized this technique in our ModiFly project and found that this can greatly improve students’ active learning and self-motivation.

For the second topic on the creation of effective plan-justification-execution-feedback loop, the student team initialized design doc, motivated by the teaming approach at Amazon. The key idea of design doc is to provide initial plan for individual tasks, including objectives, business justification, steps, and alternatives considered. Fig. 5 is an example of the developed design doc by one student working in the lab. The design doc serves two purposes. First, it provides a draft roadmap for this task. Second, it serves as a basis for other team members to communicate with respect to this task. Note that the design doc is typically designed by one student lead, who will serve as the team mentor later on, along with 1-2 additional students after debating and discussion. Once a draft design doc was created, the student lead will present it to the entire team and the project mentor for more in-depth discussion and debate. The need for “defending” the plan in front of the team will prepare students’ presentation, critical thinking, adaptation, and team working skills. Once agreed, the task will be initialized with a draft execution plan, which includes timeline, resources, and expected deliverables. To evaluate if progress has been made towards the goal, another type of doc, called demo doc, will be created by the team mentor and other team members. The demo doc shows the executed plan, progress, and outcomes, at a frequency of 4 times per year (namely, once every 3 months).

For the third topic on frequent and effective team conversation/update, we focus on creating

I2C Through LiDAR Design Doc

1. Problem Overview

The Modular Drone system mainly uses serial ports for external communication with sensors. Because there are a limited number of sensors available on the drone, we are forced to make decisions on additional features that can be added before running out of ports. This problem is exacerbated when introducing the use of LiDAR sensors. Since multiple LiDAR sensors are generally required to get the most usage out of the system through avoidance detection, having the sensors on the drone further limits the number of additional ports available. Using the I2C communication method, we are able to have multiple LiDAR sensors using only one port, freeing up other ports for additional functionality.

1.1 Business Justification

Using the I2C communication method for the LiDAR ports allows us to have multiple LiDAR sensors on one port. This gives us more ports for adding more functionality, allowing us to create more modules for customers to use in tandem with the LiDAR sensors. In addition, using I2C allows us to have additional LiDAR sensors as a module. This would mainly benefit customers wanting to use the drone indoors.

1.2 Alternatives Considered

Connecting each LiDAR sensor directly to the drone was initially considered, however, it was determined to not be feasible for more than a few sensors. For the I2C address setting, using an Arduino to change the addresses was the initial plan. However, this method did not save the new address to the LiDAR sensor. This may have been due to improper saving routines when first testing. Using the Arduino method may be beneficial in the future to avoid downloading extra software, but further testing is required.

2. Design Overview

The I2C LiDAR module was split into two main components: the hardware design and the software design.

2.1 Software Design

The software component of the I2C LiDAR module involved two parts: address setting and parameter setting. The correct settings were discovered through both the Ardupilot webpage, as well as through trial and error.

2.1.1 I2C Address Setting

The I2C address setting was necessary to ensure each I2C sensor was not using the same address. This would have caused the drone to not be able to differentiate which sensor it was receiving data from, rendering the design useless. Address setting was accomplished by using software from Benewake in order to modify each sensor. The necessary software can be found here. The Tf-Luna datasheet was utilized to get the correct instructions for modifying and saving the I2C address. The change was then verified using Arduino software to ensure each sensor had been correctly modified.

2.1.2 Parameter Setting

Certain parameters had to be modified in order to have the drone work correctly with the LiDAR sensors. The number of parameters to be changed is somewhat numerous, so the exact changed parameters for each sensor can be found here. In general, the address, orientation, type, and ranges had to be changed for each LiDAR.

2.2 Hardware Design

The hardware component of the I2C LiDAR module only consisted of soldering each sensor and installing the sensor in the correct position, as well as keeping track of each individual sensor. The soldering of the LiDARs was done in order to keep the LiDAR in I2C mode. With the Tf-Luna sensors that were used, the sensor can be operated in either I2C or serial mode. The modes were delineated by setting a certain pin to ground. Because these sensors would only be operating in I2C mode, by soldering the pin to the ground pin directly, the number of wires necessary was reduced. For installation, each sensor was marked with their corresponding address, and installed onto the LiDAR module in the correct configuration.

3. Future Steps

Future steps for the I2C module could include creating a system that bypasses the need for the Benewake software, doing further testing on the ranges for each LiDAR, and potentially introducing a way to configure additional LiDARs to the module without having to disassemble the module.

Figure 5: An example of "I2C Through LiDAR" design doc.

mechanisms to make the team communication more efficient while reducing unnecessary meetings. One of our students suggested creating Slack channel for the team to communicate daily about what was done yesterday, what is to be done today, and what the blockers are, based on his past internship experience. This method allows the team to grasp what other team members have done and need help on, without waiting to get help. Another practice suggested by the team is to maintain a working group at Teams, whose goal is to save all important files, documents, and progress. In addition, the Teams working group will be used to save all documents in the first two topics. Generally speaking, the principle behind these two mechanisms is to provide frequent yet informal updates (Slack) and infrequent yet formal updates/documentation (Teams). We are still in the process of optimizing the frequency and alternative approaches based on the busy schedule of every member.

2.2.3 Proposed Activities

The proposed activities in this thrust focus on (1) refinement of the developed teaming strategies based on team needs and limitations, and (2) active learning of advanced teaming, management, leadership skills through internships, collaborations, and projects.

Refinement of the developed teaming strategies: The adoption of new teaming strategies mentioned in preliminary activities shows its value in improving our daily team operations. Further adaptation and improvement of these strategies is needed due to the different operational environments between companies that adopt these team practices and our lab environment (university students with more demands from their courses). One the one hand, our goal is to equip students with the state-of-the-art human teaming practices such that they are prepared to move from university environments to working environments after graduation. On the other hand, the students should not be overwhelmed with the human teaming practices beyond their normal studies at school. Some of the key adaptation techniques that we plan to adopt include (1) adjustment of communication, report, presentation frequencies with a focus on the quality, (2) integration of lab projects and course projects to reduce extra workload, (3) promotion of the dynamic classroom teaming interaction experience to enhance their deep understanding of teaming strategies for the improvement of developed teaming strategies. For example, one of student projects initialized recently is a joint lab project and senior design project with participation from both the PI's lab (an undergraduate student serving as the student lead) and the senior design course (3 students serving as team members). The focus of the project is on the design of a VTOL drone module. Our goal here is to optimize our teaming strategies for the training and education of more students with diverse background and preferences.

Active learning of advanced teaming, management, leadership skills: Our current activities focus on building "team primitives" without addressing "team awareness" that can be essential in engineering workforce development. For example, many engineering tasks require the management of diverse tasks at a fast pace. It is critical to equip students with effective time management skills when dealing with diverse tasks. Our focus here is to train students on more active learning of advanced skills, including (1) decomposition of tasks into executable actions for individual team members, (2) assignment or distribution of actionable items based on team expertise and priorities, (3) evaluation and feedback at different levels, e.g., subgroup, group, task force, mission, of team operations, (4) change/update of actions, distributions, evaluation, and feedback based on team feedback, and (5) dynamic and shared leadership to encourage different role placement, experience sharing, and shared learning of advanced teaming, management, and leadership skills. One of the key features to encourage active learning is that the advanced skills will be initialized and managed by student members rather than PI. The PI will be the project mentor to provide general guidance and support. One key principle for active learning is the "trial and error" process, which allows students to try different ways before finding the best one for them. **Note that active learning promotes differences rather than standardization. Hence, the process is more important than the actual teaming strategies developed by them.** Hence, our goal here is to create an education platform for the active learning of advanced teaming, management, leadership skills through "trial and error" and then provide a general approach on how such an education platform can be designed/optimized for the education of next-generation inclusive and diverse workforce.

2.3 Testing, Evaluation, and Broad Impacts

2.3.1 Background and Objectives

Testing and evaluation of the proposed training and education activities on diverse STEM topics and human teaming effectiveness topics serve as a feedback mechanism to assess the value and impacts of the proposed activities. The proposed lab activities provide important initial steps towards building a basic and fundamental mindset. The new mindset needs to be reinforced in numerous activities, especially in a competitive environment under time constraints. To further hone the learned technical and teaming skills, the *objective* of the thrust is to engage students in several activities during the course of the project. Another objective is to promote active learning though acting, thinking, and working beyond their "comfortable" environments. **Our philosophy is that successful STEM education should provide students necessary "tech awareness" and "team awareness" for their lifelong learning and eventually training/education of more students for broad impacts.**

2.3.2 Preliminary Activities

Our team members have participated in several activities to apply their learned technical and teaming skills, through which they learned new lessons and gained confidence/interest to further develop their technical and teaming skills. Our department and college offers capstone project competitions every semester to showcase the senior design projects by all engineering students. The competition features capstone projects including demo, presentation, and evaluation by industry companies and academic professionals, hence providing great opportunities for students to manage team efforts towards team objectives under time constraints. In Fall 2021, 3 undergraduate students from the PI's lab formed a team, called ModiFly, to demonstrate the modular drone project. Among all students in our department, the ModiFly team won the first place in the department with great comments from the judges about their team efforts, demonstrated in their presentation, demos, and report. In Spring 2022, the ModiFly team was selected to represent the university (only one team per university) to participate in the the ECEDHA Senior Design Showcase, held yearly for institutions from the Southwest Region (Texas, New Mexico, and Arizona). The ModiFly team won both the first prize and the Entrepreneurial Award, shown in Fig. 6. The judges and other institution representatives were impressed by the techni-

Figure 6: The ModiFly team from the PI's lab won the first prize (top) and the Entrepreneurial Award (bottom) at the 2022 ECEDHA Senior Design Showcase, held in Dallas, TX.

cal novelties, presentation skills, and potential towards commercialization. It is important to note that the project was managed by the students directly with the PI serving as the project mentor.

2.3.3 Proposed Activities

The proposed activities in this thrust focus on (1) continuous participation in competitions, and (2) students internships/jobs in national labs and industrial companies.

Continuous participation in competitions: Learning of technical and teaming skills requires frequent usage to develop appropriate mindset and behaviors towards lifelong learning. The PI recognizes the importance of exposing students to different environments, especially those different from lab environments, for their active adaptation and optimization of learned technical and teaming skills beyond their comfort zones. Our preliminary studies show the value of activities proposed in the first two thrusts towards building students' "tech awareness" and "team awareness". In particular, participation in competitions is one of the notable methods to push students actively learn and shape their technical and teaming skills because of the competitive nature of competitions under time constraints. Here are a few competitions that our students are anticipated to participate in. First, we will take advantage of the the capstone project competition, organized by our college and department every Fall/Spring semester, to initialize student teams from both within and outside of the lab. Based on the activities in the first thrusts, the students will be trained on technical and teaming skills for the development of new mindset on "tech awareness" and "team awareness". Second, we will work with the department to form a strong team for the annual ECEDHA Senior Design Showcase from the Southwest Region (Texas, New Mexico, and Arizona). Another unique opportunity is the drone competition, organized yearly at San Antonio, open to both high school and college students (`https://2022.dasconline.org/student-unmanned-aerial-systems-competition/`). The high school and college students are anticipated to participate the drone competition yearly. Finally, San Antonio also hosts yearly events such as ForceCon, which is a great opportunity for students to engage and participate. The PI will also promote the participation in additional UAV competitions (`https://www.computer.org/publications/tech-news/events/uav-2022`) to train the team's organizational, teaming, management, and communication skills under time and budget constraints when such opportunities arise.

Students internships/jobs in national labs and industrial companies: Learning from other organizations, especially national labs and industrial companies, is essential for the continuous training and education of our students. The PI will help connect students with national labs and industrial companies for internship opportunities and full-time jobs. We will invite our alumni to share their experiences with the team and internship/job opportunities within their companies and/or their connections. We will work with our DoD partners/collaborators to hone the students' technical skills and communication skills for the development of next-generation diverse and inclusive workforce with not only outstanding tech and team awareness but also an open mindset toward active learning of new tech and team skills. As a common practice in the lab, new skills learned by our students during their internships will be debated and integrated into our in-house training/education program after proper adjustment. Our goal is to create a lifelong learning environment in the lab such that all students in the lab will gradually build a habit of working towards a career with active lifelong learning, which is essential for the development of next-generation workforce for the U.S. Navy and beyond.

3 Naval Relevance

To fulfill Navy's mission to "maintain, train and equip combat-ready Naval forces capable of winning wars, deterring aggression and maintaining freedom of the seas", it is essential to train and educate next-generation diverse and inclusive workforce in artificial intelligence and autonomy with both technical and teaming mindsets. Creating a systematic STEM educational pathway for sustainable workforce development for inclusive and diverse U.S. citizens, regardless of technology domains, is of great interest to the United States Navy and beyond. One key challenge is the acquisition of diverse STEM topics for their preparation of future engineering careers in U.S. Navy and Marine Corps because of the diverse skillsets needed in the operation of autonomous systems in Navy domains. For example, we are currently working on developing new learning strategies from failure funded by ONR. The fundamental research in this project will be integrated with the proposed STEM activities to train/educate students with necessary skills for the application of the fundamental research in Naval robotic platform. Another key challenge is to prepare students with the critical teaming mindsets because many Naval missions, if not all, require the teaming and collaboration of scientists, engineers, operators, commanders, etc., with diverse background. Equipping students with essential mindsets in teaming, collaboration, time/task/progress management, communication, and leadership plays an important role in maintaining the superiority of future Naval workforce. This STEM project also involves the development of partnership with Naval labs to train/educate students with skills and mindsets for their future careers in Navy and beyond. In short term, the proposed STEM activities aim to fulfill current needs at the US Navy by providing diverse and rich technical and teaming skills in autonomy and AI. In long term, the proposed STEM activities aim to provide some fundamental guidelines and principles for a sustainable and scalable engineering workforce pipeline, which are critical for future Navy and DoD missions.

4 Project Schedule and Milestones

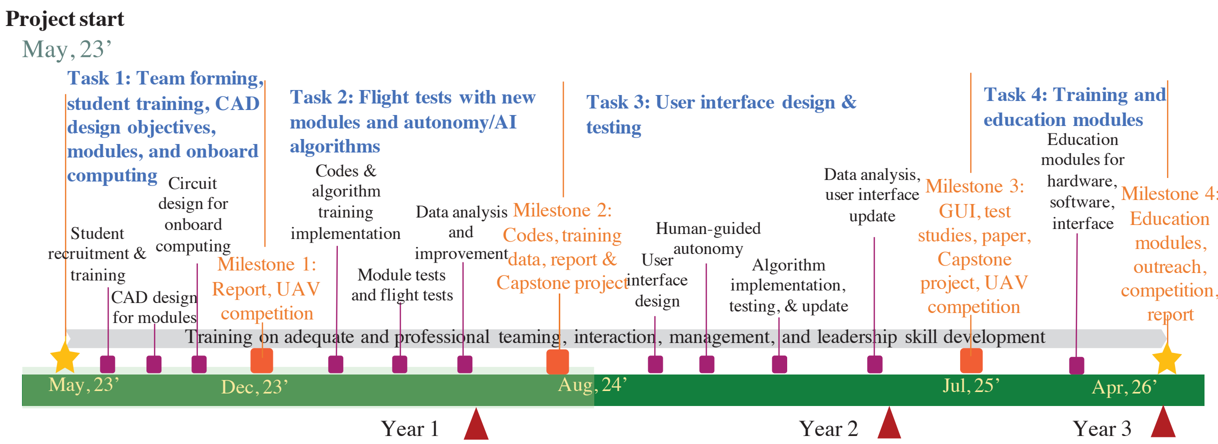

Figure 7: The estimated project schedule and milestones.

5 Reports

The PI acknowledges the following reports required under ONR funded STEM Efforts:

- Annual Reports: We will use the provided template to submit a complete annual Research Progress Report mandated by ONR.
- Annual ONR STEM program Data Call Form: We will follow the manual and template provided by ONR to provide required information, including, e.g., overview, metrics, budget information, accomplishments, etc.
- Final Report - We will submit a final report that details the full programmatic accomplishments summarized and contribution to naval needs as the funding ends. If applicable, we will include examples of solutions to address ONR STEM needs.

6 Evaluation Approach

As the project focuses on the development of new active learning STEM education approach, our evaluation approach will focus on effectiveness and impacts. We will evaluate the effectiveness based on students' achievements, including, the number of student interns, awards, and papers/inventions/patents generated. In addition, the students' job placements after graduation will be used as an indirect metric since students may not start working soon, especially for high-school students. We will keep this job placement/growth metric as an ongoing effort even after the end of the project. We will evaluate the impacts based on the number of students involved, participated competitions, students with diverse background, additional students who are trained under the project but not supported by the project.

7 Management Approach

Dr. Yongcan Cao is the principal investigator of the project. He also serves as the manager of the project. During the course of the project, 1 graduate student and 3 undergraduate students are expected to perform the day-to-day tasks. 2 high-school students will be trained during the summer semesters during the course of the project. The PI will ensure that progress is made towards each goal and milestone. No other subcontractors/subrecipients will be involved in this project.

8 Qualifications

The PI has over 13 years' experiences in research on autonomous systems and robotics with both civilian and military applications, such as remote sensing and surveillance. He has over 3 years' experience working in the Air Force Research Laboratory and over 8 years' collaboration with the Air Force Research Laboratory. The proposed research is based on his past research experience to address numerous challenges, including UAV control and cooperation, robot decision making, integrated defense using heterogeneous robots, machine learning, and human-robot teaming, for DoD. Part of his work has been transitioned to the DoD operations through the Intelligent Control and Evaluation of Teams program, Loyal Wingman program, and the Exercise Talisman Sabre, one of the largest military exercises held by U.S. and the allies. For example, one of the UAV circumnavigation algorithms that the PI developed has been tested on F-16 via the Loyal Wingman program. More specifically, he has recently conducted innovative research on risk-aware robotic decision making, information reliability, human-guided robotic control, GAN-based human preference learning, model compression, and deep reinforcement learning, evidenced by 43 journal articles, 66 conference papers, 1 book chapter, and 1 book with 10000+ citations. The PI is currently directing the Unmanned Systems Lab (approximately 1000 square feet) with numerous unmanned systems, including UAVs (ArDrone, Bebop, Qball, Lab-designed Modular Drone), ground robots (Turtlebots), computers with GPUs, and in-door localization system (Quanser OptiTrack). The PI and his students have conducted numerous successful tests on single- and multi-UAV control and target tracking enhanced by numerous deep learning modules. The lab has hosted approximately 200 visitors nationwide including DoD agencies (Army, Navy, and Air Force), industry companies (Intel, SwRI, and HEB), and national labs (DOE and NASA).

9 Responsibilities

Resources and ability to obtain resources

The PI is currently the director of the Unmanned Systems Laboratory in the Department of Electrical and Computer Engineering at the University of Texas, San Antonio. The lab currently has a few unmanned platforms, including unmanned aerial vehicles such as Ar.Drone 2, DJI Phantom, Parrot Bebop 2, Lab-designed Modular Drone and the Quanser Qball 2 quadrotor system (`http://www.quanser.com/products/qball2`), unmanned underwater vehicles (OpenROV), and ground robots (Turtlebots). The lab also has ample space for 10 students. The Quanser Qball 2 quadcopter system has been successfully setup and tested in the lab (see `https://www.youtube.com/watch?v=0vcqbEFBivw&t=2s` for a demo video).

Other resources: (1) Computer: the PI has personal computers in his office. Each student is also provided with a PC. All computers have a mix of licensed software and freeware available. We also acquire four computers with GPU processing for the training of deep learning algorithms to be developed in this project. The Office of Information Technology at UTSA provides full service from network connection to software installation to information security. (2) Cloud computing resources: The PI's home institution has dedicated cloud computing institute, Open Cloud Institute, that can offer both computational resources and technical support to run programs on the available cloud clusters for research and education. We will leverage these resources in the project as needed.

Ability to comply with the grant conditions

Dr. Yongcan Cao will serve as the principal investigator and will take overall responsibility of the proposed research. He will devote 1 academic month each year on this project to ensure that progress is made towards the goals and milestones. Other than his teaching, research, and service duties to the university and the scientific communities, he will also contribute to the project through recruiting team members, managing project progress, providing guidance and support, and evaluating the alignment of project efforts to the project objectives through the entire period of the project. The PI will also communicate with program manager to ensure the continuous alignment of our efforts on the project to the Navy, especially STEM, needs. The PI currently has five active projects, in which he serves as the PI/Co-PI and will contribute 3 summer months' efforts. The PI will ensure that he fully complies with the grant conditions.

Performance history

Dr. Yongcan Cao has served or is currently serving as the PI for seven federal grants: one from Air Force Office of Scientific Research (AFOSR), three from Office of Naval Research (ONR), one from Air Force Research Lab (AFRL), one from Army Research Office (ARO), and one from Army Research Lab (ARL). He has successfully completed the project funded by AFOSR and one project funded by ONR. Numerous conference/journal papers on the proposed efforts have been delivered for the two projects. For the other active grants, he has recruited 5 PhD students, 1 Postdoc, and 6 undergraduate students. The PI is expected to recruit 1 new graduate student, 3 undergraduate students, 2 high-school students in Spring/Summer 2023. The awarded amount will be expended to the new students. Hence, any future awarded amounts will be expended separately from other projects.

Record of integrity and business ethics

The PI always follows all university, federal, and program manager's policies/guidelines/requests when performing the proposed activities in past and current projects. In particular, the PI finished all required university training on conflict of interests, research concerning human subjects, export control, and information security. He also followed grant rules to report project progress, provide reports to program manager, participate in program reviews and panel meetings, and provide inputs to develop further program activities. He also provided timely training for his students/postdoc to ensure that they all follow university/federal policies when conducting the specific research tasks. The PI strives to achieve the highest integrity and business ethics through the entire period of project and will fully cooperate with university/federal government/program manager. The PI has no past record of violating any integrity and business ethics.

Qualifications and eligibility to receive an award

The PI is currently an associate professor at the University of Texas at San Antonio (public research university in the state of Texas). He is a U.S. Citizen. He is eligible to receive an award from ONR under BAA N00014-22-S-F006.

Organization, experience, accounting, and operational controls and technical skills

The PI's home institution, University of Texas at San Antonio (UTSA), is a public institution in the State of Texas with R1 designation from the Carnegie Classification of Institutions of Higher Education. UTSA has rich experience in conducting federal grants, cooperative agreements, and contracts from DoD (Army, Air Force, and Navy), NSF, NASA, DOE, DOT, DHS, NIH, etc. UTSA has organizations/entities that manage accounting, operational controls, quality assurance, export control, human subjects, and safety control for all sponsored projects, including this project.

Facilities and Equipment

The PI is the director of the Unmanned Systems Laboratory. The lab is about 1000 square feet in size and has the following facilities that can fulfill the need of the project: Quanser OptiTrack (1); Quanser Qball (8); Turtlebot (4); ArDrone (3); DJI Phantom (5); Computer (12): four GPU computers for high-performance computing; Lab-designed Modular Drone (1); and Pioneer P3-DX (3). If needed, the PI and his students can also get free access to the cloud computing facilities in the Open Cloud Institute at the University of Texas, San Antonio. It is not expected that any Government Furnished Equipment/Hardware/Software/Information will be required for this project. However, we will discuss with the program manager if any government facilities are needed during the course of the project.